Optimal Network Design to Detect Spatial Patterns and Variability of Ocean Carbon Sources and Sinks from Underway Surface pCO_2 Measurements

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PROJECT SUMMARY
In agreement with the Intergovernmental Panel on Climate Change (IPCC), the *Second Report on the Adequacy of the Global Observing System for Climate in Support of the United Nations Framework Convention on Climate Change (UNFCCC)* concludes that there remain serious deficiencies in the ability of the current global observing systems for climate to meet the observational needs of the UNFCCC. One continuing aspect of the effort to redress the identified deficiency has been to expand the surface ocean pCO_2 measurement program in order to quantify our understanding of the seasonal and interannnual variability of air-sea CO_2 fluxes in the world oceans. While there is a reasonably good understanding of the major sources and sinks of CO_2 based on the sea surface pCO_2 climatology developed by Takahashi et al. (2002), the motivation for this study is to produce the optimal global pCO_2 sampling network design to provide a region-by-region estimate of the sampling required to quantify fluxes of CO_2 to the nearest 0.1 Pg C/year, updating and expanding the preliminary effort of Sweeney et al. (2002).

International Linkages:
Research strategies for global carbon cycle studies have been developed by various working groups of programs like the International Geosphere-Biosphere Programme (IGBP), the World Climate Research Programme (WCRP), the International Human Dimensions Program (IHDP), and the Intergovernmental Oceanographic Commission (IOC) working together. Our project is in support of the need for global-scale coordination of international carbon observation and research efforts in order to achieve the goal of a global carbon synthesis. This study fulfills one component of the urgent need to critically assess the overall network of planned observations to ensure that the results, when combined, will meet the requirements of the research community. By providing an optimal network design for a global pCO_2 measurement program, we will directly contribute to the International Ocean Carbon Coordination Project (IOCCP).

Relationship to NOAA's Program Plan for Building a Sustained Ocean Observing System for Climate: (Objective 8: Ocean Carbon Monitoring Network)
Optimal design of the pCO_2 sampling network design using both the global database of pCO_2 measurements and simulations of future climate from GFDL's Earth System Model will help NOAA cost-effectively develop the infrastructure necessary to build, with national and international partners, the ocean component of a global climate observing system. The goal of this data and model-based pCO_2 sampling network design is to quantitatively assess the optimum sampling strategy based on the ongoing long-term observational requirements of the operational forecast centers, international research

programs and major scientific assessments.

DELIVERABLES

By the culmination of this study (July 31, 2008), we will have provided the following deliverables:

1) A peer reviewed assessment of spatial and temporal variability of surface ocean pCO_2 and the associated air-sea CO_2 fluxes now and into the future.

Status: Currently undergoing internal review prior to submission

2) A recommendation of the optimal sampling network design needed to capture the variability of air-sea CO_2 fluxes in a way that will reduce the errors in regional scale estimates of the seasonal and annual air-sea CO_2 fluxes to +/-0.2 Pg-C/yr. The network design will make recommendation in the following categories:

- Sampling frequency
- Spatial distribution
- Distribution and type of surface ocean pCO_2 measurement platforms

Status: Near completion – undergoing incorporation of Takahashi dataset.

ACCOMPLISHMENTS

1) We have added several new datasets to our global pCO2 database raising the total number of measurement to **1.8 million** (Figures 1). Very recently (this month), the entire Takahashi pCO_2 dataset with over **3 million** measurements became available through CDIAC and we are incorporating these data (some of which were already included) into our database. We anticipate having approximately 4.5 million measurements in our database when the Takahashi data is fully integrated and duplicate measurements are weeded out. Our analysis with this newest data is still underway.

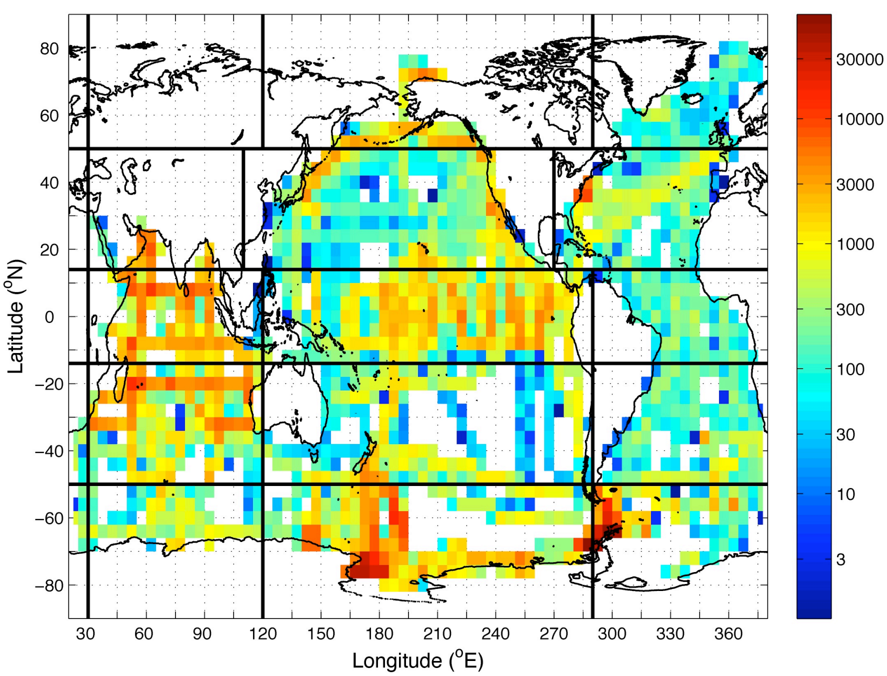

Fig. 1. The number of pCO_2 measurements in the assembled database (pre-Takahashi release) binned into 4° by 5° boxes, independent of time of year.

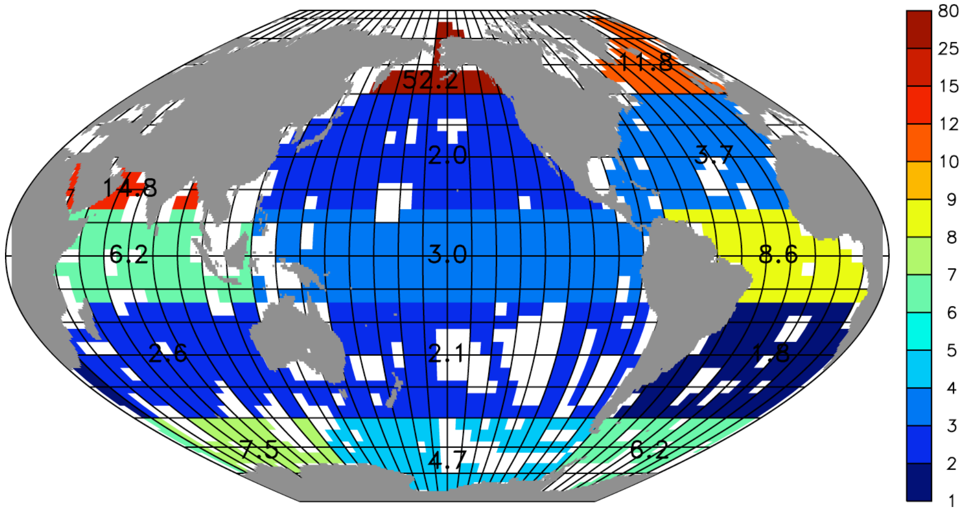

Fig. 2. Target ΔfCO_2 to estimate a regional CO_2 flux within ± 0.1Pg-C/yr for the major oceanic regions.

Table 1 shows that estimation of a regional CO_2 flux to within ± 0.1 PgC/yr for the major oceanic regions requires that the sea-air fCO_2 difference be determined to within 2 to 12 µatm. Small oceanic regions such as the Polar North Pacific and Temperate North Indian Oceans (area < 7 x10^6 km^2) fall outside this range since the net flux for these areas are much smaller than 0.1 PgC/yr.

Ocean Regions	Ocean Area (10^6 km^2)	Average ΔfCO2 (µatm)	Annual Flux (PgC/yr)	ΔfCO2 per 0.1 PgC/yr uptake
Polar North Atlantic	7.05	-45.2	-0.18	11.8
Temperate North Atlantic	23.71	-19.0	-0.25	3.7
Equatorial Atlantic	17.13	11.2	0.06	8.6
Temperate South Atlantic	24.38	-8.4	-0.22	1.8
Polar South Atlantic	9.89	-5.9	-0.05	6.2
Polar North Pacific	5.26	-15.3	0.01	52.2
Temperate North Pacific	42.01	-19.5	-0.46	2.0
Equatorial Pacific	50.67	17.6	0.28	3.0
Temperate South Pacific	36.50	-15.2	-0.34	2.1
Polar South Pacific	16.53	-12.6	-0.13	4.7
Temperate North Indian	4.15	35.3	0.12	14.8
Equatorial Indian	18.61	13.0	0.10	6.2
Temperate South Indian	26.94	-25.9	-0.48	2.6
Polar South Indian	7.27	-9.3	-0.06	7.5
Global Oceans	290.09	-6.9	-1.61	0.2

Table 1 – Mean annual sea-air fCO_2 difference, annual flux and the sea-air fCO_2 required for 0.1 Pg C flux. All the values are from the assembled fCO_2 database. The long-term mean wind speed data from NCEP and the wind speed dependence of gas transfer coefficient of Sweeney et al. (2006) have been used.

2) We have reanalyzed our results using the new gas-transfer velocity from Sweeney et al. (2006) which has resulted in a 33% reduction in our target estimates (Fig. 2, Table 1).

3) We have broken the available data down into seasonal and monthly components to analyze the temporal aspects of the global air-sea carbon exchange for each region. Our length-scale analysis for each season is nearly finished, but preliminary results indicate that only a few locations (e.g. the Northern Indian Ocean which has much higher variability in the summer) would require much different spacing than was determined with the annual data (Figure 3).

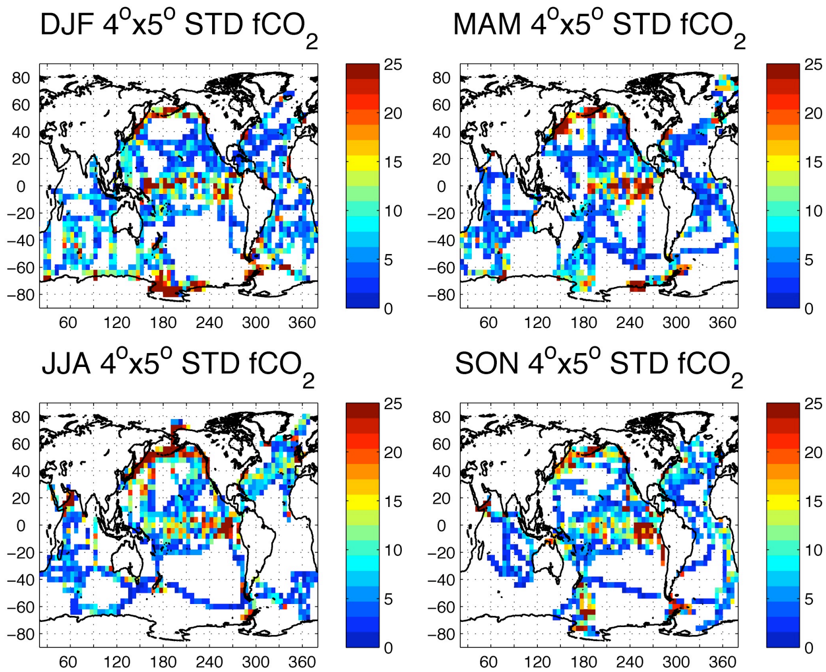

Fig. 3. Standard deviation of fCO_2 observations for each season. Most locations for which we have measurements have similar variability during each of the four seasons.

4) We have finished our spatial *decorrelation length scale* analysis of the pre-Takahashi database. This analysis uses a simple approach to resampling a series of data which assumes that a *linear interpolation* of the data set represents the true data set. We merely look at the interpolated data and resample the INDEX at regular intervals. The subsampled data (equal number of samples away from each other) is then linearly interpolated and resampled at the original sampling resolution from which a comparison is made. This routine is meant to estimate what kind of sample spacing you might need to get a standard deviation within 5% of the range in the original data.

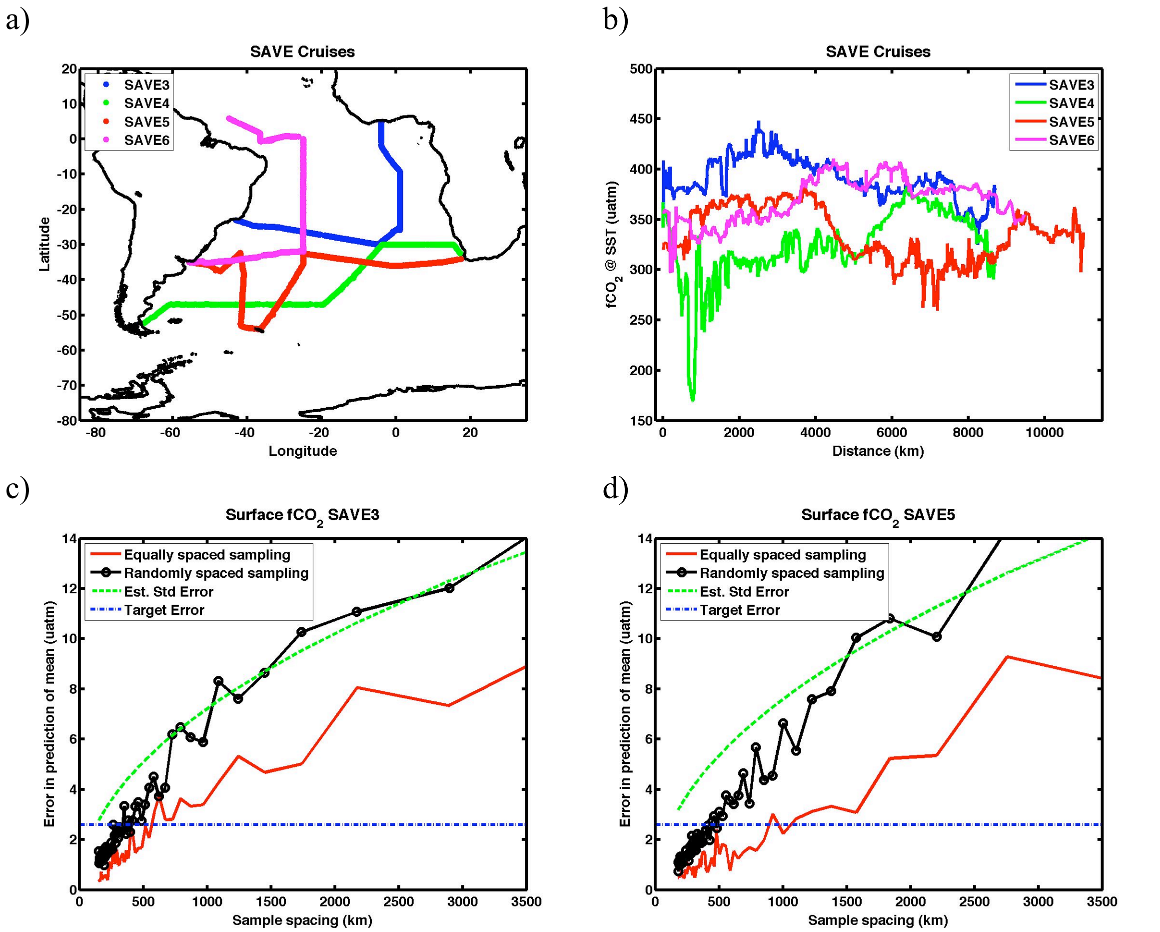

Fig. 4. The (a) cruise tracks; (b) measured fCO_2 for some of the cruises in our database (c,d) decorrelation length-scale analysis of 2 of these cruises. In (c,d) the standard error in the mean is indicated in green, sampling with equal space-intervals in red, sampling with randomly spaced intervals in black with circles, and the blue line indicates the target ΔpCO_2 needed to estimate the flux of CO_2 to the nearest ±0.1 Pg of C/yr in the temperate South Atlantic

As an example, we present the data two cruise tracks (SAVE3, SAVE5, Fig 4a,b) and the results our method provides for estimating the observed variability within the data based on regularly spaced samples (Fig.4 c,d). For the SAVE3 cruise, randomly spaced subsamples at ~350km and regularly spaced subsamples at ~600km approximate the observed variability in the data to with the 5% necessary, in order to estimate the total air-sea flux for this region to within ±0.1 Pg. For the SAVE5 cruise, regularly spaced measurements at ~1000km would achieve the desired accuracy. Our analysis of the entire assembled dataset on our targeted 4° by 5° grid is presented as Figure 5.

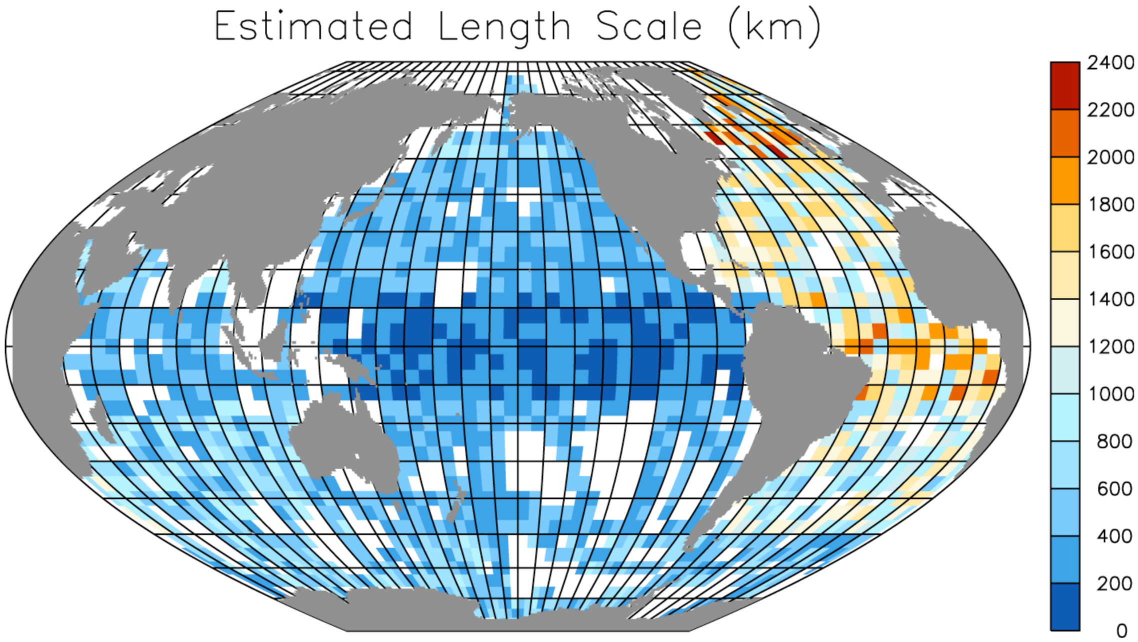

Fig. 5. Preliminary calculated length-scale for regularly spaced measurements necessary to capture the observed variability in order to estimate the total regional air-sea flux of CO_2 to within ±0.1 Pg (more data and analysis required for complete estimate).